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Data processing in the Meteorological Office Short-period Weather Forecasting Pilot Project

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Summary

The Meteorological Office Short-period Weather Forecasting Pilot Project, which began in 1978, required the development of techniques for processing radar and satellite imagery. In this paper the data-processing system is described which enables data from several radars to be combined with data from Meteosat to give the mesoscale pattern of precipitation. The resulting data are presented within a minicomputer environment to small teams of research meteorologists and forecasters. The system is structured as a distributed processing minicomputer-network mostly using dedicated communications lines rented from the Post Office. Instantaneous fields of precipitation, and rainfall totals integrated for short time-periods over areas defined by users, are distributed from each radar site to a number of Meteorological Office and Water Authority users, who are at present assessing the usefulness of the data for real-time operations. The software modules which are used in this system are discussed and the data archives which are being created are described.

1. Introduction

The aims of the Meteorological Office Short-period Weather Forecasting Pilot Project have been listed by Browning (1977) as:

(i) To establish and operate facilities to provide mesoscale observational fields of cloud and precipitation (albeit at first over only a part of the country in the case of some of the data), and, in the light of practical experience, to optimize the accuracy, reliability, and the clarity and timeliness of presentation, of the data.

(ii) To exploit these data to improve our understanding of the structure, mechanism, evolution, and predictability of precipitation and associated wind systems.

(iii) To develop simple analytical procedures to optimize the use of these data for the provision of improved forecasts of precipitation and wind (initially over a period of a few hours, but with a view to extending the period of improved forecasts up to 6 h or longer).

(iv) To assess from practical experience the utility of the actual and forecast fields of precipitation to users.

(v) To assess the desirability, and most cost-effective way, of extending the mesoscale observational network and forecasting techniques.

The Project is primarily concerned with the measurement and forecasting of surface precipitation. Although data from several levels in the atmosphere will be collected, these are intended solely to improve the estimates of the precipitation reaching the ground.

Mesoscale observations of precipitation and cloud have been greatly improved by recent advances in real-time radar data processing and satellite imagery. Work on quantitative rainfall measurement by radar (for a review see Wilson and Brandes, 1979), together with the considerable work reported in the literature on the use of radar for general weather surveillance and analysis (for a review see Browning, 1978), provided the impetus for the use of radar as a key element in the mesoscale observational system. Work over several years at Malvern (Taylor and Browning, 1974) has led to the development of digital methods whereby data from several radars, equipped with on-site minicomputers, can be transmitted to a central location and composited automatically to give a map of the precipitation distribution over a large area. Moreover, the advent of the geostationary weather satellite, Meteosat, providing half-hourly cloud imagery over an area including the United Kingdom, has also made the use of satellite cloud data for very-short-period weather forecasting a realistic proposition.

Most of the work to date in the Pilot Project has been aimed at achieving aim (i) above. This has involved establishing an extensive data communications system linking a number of minicomputers providing data from a number of radars and from Meteosat. Software systems have been prepared in order to accomplish both real-time and off-line data processing. Detailed descriptions of these systems will appear elsewhere. The purpose of this paper is to describe briefly the data-processing system as a whole, emphasizing how data will be provided to accomplish the other aims of the Project specified above.

2. The Pilot Project data network

2.1 *Principal sources of data*

The radar network now being used consists of four radars (Figure 1). Details of the actual radar hardware are given by Ball *et al.* (1979b), and in several internal Met O RRL reports. The radars at Camborne (Cornwall) and Upavon (Wiltshire) are old Plessey 43S radars (10 cm wavelength, 2° beamwidth) sited in a non-optimum manner, and therefore give somewhat limited coverage compared with the other two radars. The radar at Clee Hill (Shropshire) is a Plessey 43C radar (5·6 cm wavelength, 1° beamwidth), which has an horizon at or below 0° in virtually all directions. The 43C is the radar that was operated until recently at Llandegla as part of the Dee Weather Radar Project. The radar at Hameldon Hill, near Burnley (Lancashire), is a new Plessey 45C radar (5·6 cm wavelength, 1° beamwidth). The Hameldon Hill radar forms part of a separate project, known as the North West Radar Project (Collier *et al.*, 1980) (see Appendix A). The Camborne, Upavon and Clee Hill sites are manned (in the case of Clee Hill, Civil Aviation Authority personnel are close by, but no Meteorological Office staff are on the site). The Hameldon Hill radar is completely unmanned, and represents the first such quantitative weather radar in the British Isles. These radars are capable of producing precipitation data at one-minute intervals with a minimum resolution of about 1 km, although resolutions of 5 min and 2 or 5 km are used in the Pilot Project. Personnel at the Met O RRL Malvern, and local technical staff of the Meteorological Office Maintenance Organization (Met O MO) are operating the radars at Camborne, Upavon and Clee Hill 24 hours a day. The Hameldon Hill radar system, on the other hand, will be regarded as operational from about the beginning of 1980, and its maintenance will be undertaken jointly by local (Aughton) Met O MO staff, and staff of the North West Water Authority.

The satellite, Meteosat*, is in a geostationary orbit over the equator, and is capable of providing infra-red (IR) and visible (VIS) cloud imagery at 30 min intervals with a resolution in the IR at 50°N

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* Meteosat 1 ceased operating in November 1979; Meteosat 2 is expected to be launched in September 1980.

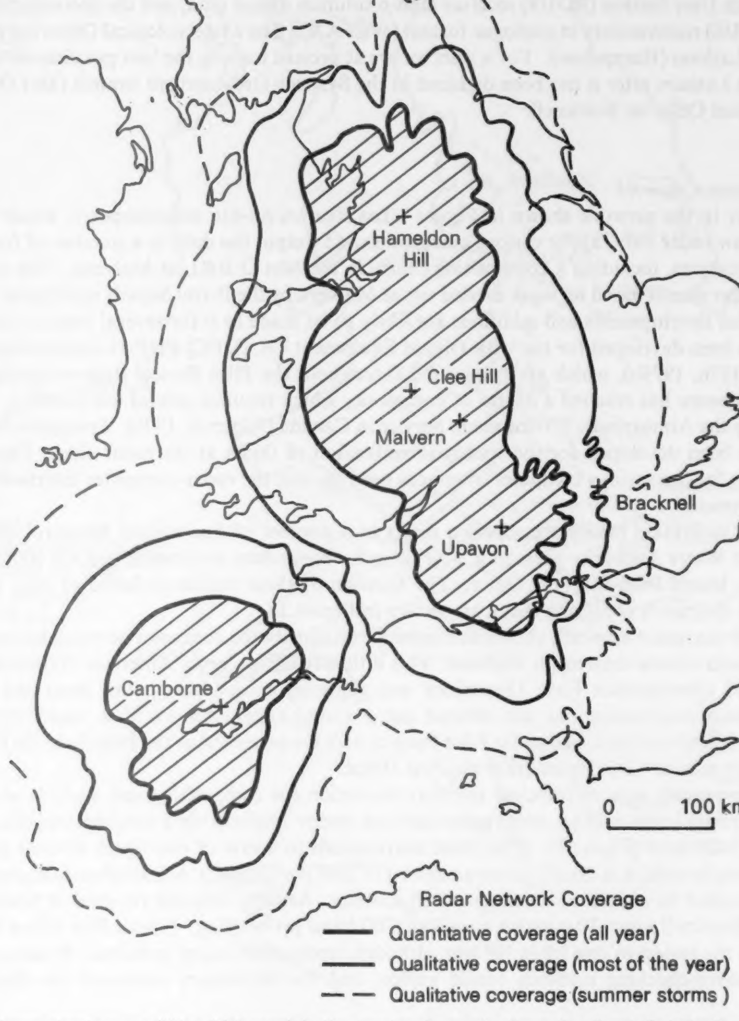

Figure 1. Approximate area within which precipitation can be observed using radars located at Camborne (Cornwall), Upavon (Wiltshire), Clee Hill (Shropshire), and Hameldon Hill (Lancashire). Areas with potentially quantitative coverage are shaded, and the areas of qualitative coverage are enclosed by a broken line.

of 6 km E–W and 12 km N–S (plus some overestimation of the northward extent of cloud because of the oblique angle of view). These data are received at a central ground station in Darmstadt (Federal Republic of Germany) for processing, archiving and redistribution to real-time users via Meteosat

itself (Morgan, 1978). There are two types of user receiving station: primary and secondary. The Primary Data User Station (PDUS) receives high-resolution digital data, and the Secondary Data User Station (SDUS) receives data in analogue format (WEFAX). The Meteorological Office has established a SDUS at Lasham (Hampshire). For a start we are at present making the best possible use of imagery obtained via Lasham after it has been digitized in the Systems Development Branch (Met O 22) of the Meteorological Office at Bracknell.

2.2 *The computer network*

Each radar in the network shown in Figure 1 has its own on-site minicomputer, which is used to accept the raw radar data, apply various corrections and output the data in a number of formats to a variety of locations, including a compositing centre in the Met O RRL at Malvern. The software in use at the radar sites is based on work carried out at Malvern by the Royal Signals and Radar Establishment. Further developments and additions are likely to be made to it for several years to come. This software has been developed for use with Digital Equipment Co. (DEC) PDP-11 series minicomputers (Ball *et al.*, 1976, 1979b), which are being used throughout the Pilot Project data-processing system. The radar software has reached a degree of complexity which requires special test facilities, similar to those used by the Atmospheric Environment Service in Canada (Aldcroft, 1976). Specialized diagnostic software has been developed for the speedy identification of faults at the radar sites. This software provides tests for the various computer interfaces used on site, the radar–computer interface unit, and the display system.

Data from individual radars are supplied direct to a number of operational Meteorological Office locations and Water Authority users in a 3-bit format. These data are transmitted via 600/1200 baud private wires leased from the Post Office. The location of these outlets (referred to later as Jasmin outputs) and the radars supplying them, are shown in Figure 2.

The overall computer network, shown in Figure 3, is a distributed computer network having a radial communications system centred on Malvern. This differs from the larger American National Weather Service AFOS (Automation Field Operations and Services) computer network described by Klein (1976), in which communications are effected using a ring system known as a 'multidrop' system. All the communications lines used in the Pilot Project, with the exception of the links from the Hameldon Hill radar, are private wires leased from the Post Office.

In order to provide data of sufficient intensity resolution for compositing and analysis at Malvern, 8-bit (208 intensity levels only are used) radar data are sent to Malvern via a synchronous line network, operating at 2400 baud (Figure 4). (One baud corresponds to a rate of one signal element per second in an equal-length code; it is usually taken as one bit of data per second.) A field of surface precipitation data is transmitted from each radar site every 15 minutes. Satellite data are received at Malvern from Lasham via Bracknell every 30 minutes via a 600/1200 baud private line. Private Post Office lines have error rates in the region of one bit in 10^6 bits, although errors often occur in bursts. It was considered that simple error-checking methods would suffice, and the techniques employed are described in Appendix B.

Several computers are located at Malvern (Figure 3). One of them, a PDP11/40, is referred to as the Network computer. Data from the individual radar sites are fed at 15-minute intervals into this computer, which generates the radar composite pictures and records them on magnetic tape. Satellite data are also received into this computer and archived on magnetic tape. The radar composite data are passed in near-real-time to a further PDP11/34 computer known as the Display computer. This computer is employed to reformat and merge the radar composite and satellite data for flexible use by a team

Figure 2. Illustration of the communication-line network connecting various existing (solid line) and planned (dashed line) users to the radars. All the lines shown carry 3-bit data and are land-lines leased from the Post Office and operated at a data rate of 600/1200 baud.

of forecasters at Malvern. The display-computer software, although relatively simple at present, is being enhanced in line with the FRONTIERS program described by Browning (1979).

Development of the radar-site software is carried out at Malvern on a further PDP11/34 computer.

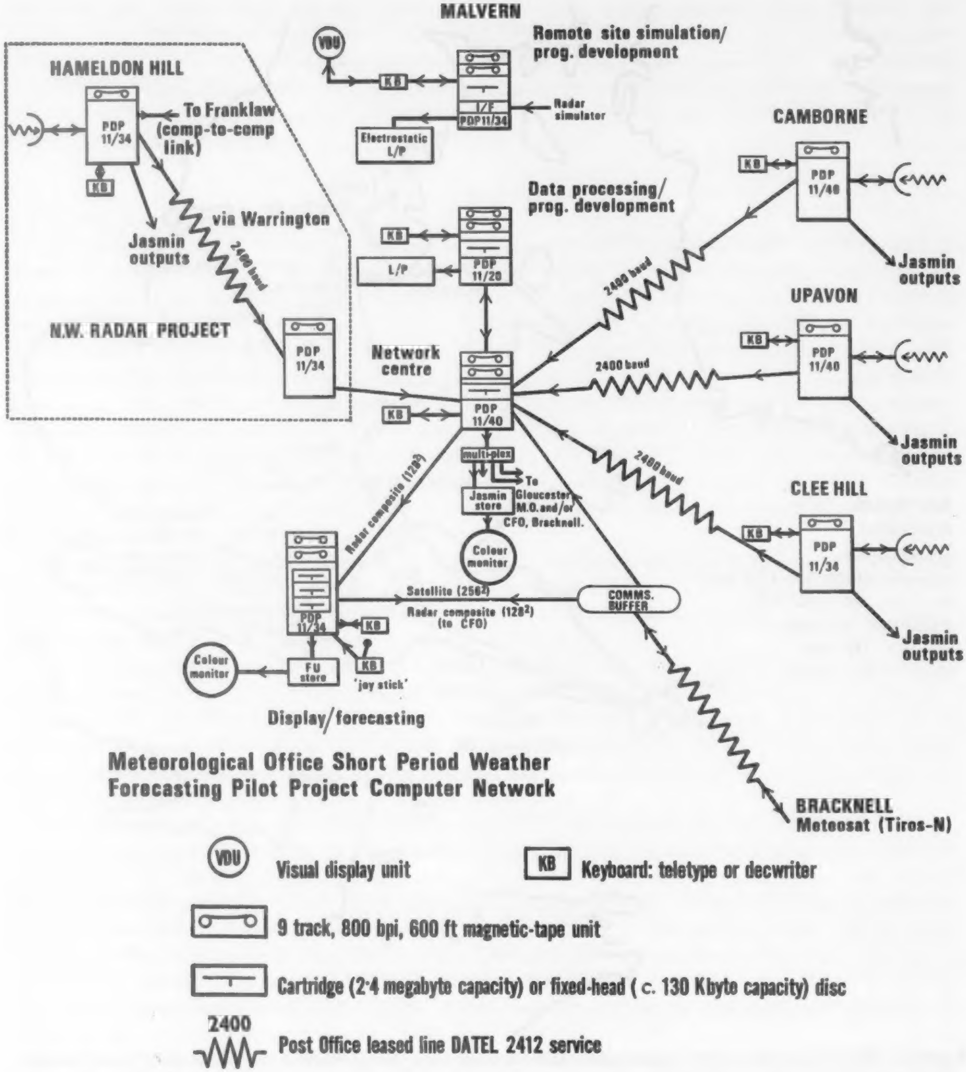

Figure 3. The type, location and interrelation of the minicomputers making up the Pilot Project computer network.

Figure 4. The communications network connecting the radars to the Meteorological Office Radar Research Laboratory at Malvern. All the lines (except the microwave link used in the North West Radar Project) are land-lines leased from the Post Office and operated at a data rate of 2400 baud.

Radar video data and azimuth interrupts may be simulated on this computer with a version of the electronic radar–computer interface used at the radar sites (Ball *et al.*, 1979a), and an analogue-to-digital unit provided with data from a simple clocked electronic signal generator. This facility allows the radar-site software to be developed and tested at Malvern before being passed to the radar sites. Routine off-line data processing, such as the provision of hard copy, is also carried out on this computer, and on a further (PDP11/20) computer. The above computers at Malvern (with the exception of the Network computer) have magnetic tape drives and a removable disc capability. This enables software to be developed on one computer and easily used on another computer.

All the software developed in the Met O RRL has been written using PDP MACRO-11 assembly language, although a variety of subroutines (MACROs) have been developed to provide programmers with certain facilities usually only found in high-level languages (Davy, 1974). These facilities have aided rapid software development, and given a degree of program self-documentation. The operating system used at Malvern has been DEC DOS-11, but this has been upgraded to RT-11 Version 3.

3. Real-time data processing

3.1 *Data processing at the radar sites*

Ball *et al.* (1979b) have described the software system which forms the basis of that used at the radar sites. No commercial operating system is used at the sites, the intention being to keep the on-site

computer hardware configurations as small and as simple as possible. Nevertheless, the software is still complex, involving several nested interrupt routines whose priorities are a function of time. The primary tasks carried out in real time within the main radar data-processing software modules may be summarized, in the order in which they are carried out, as follows. Some of these tasks remain to be fully implemented, and some differ from those described by Ball *et al.* (1979b).

- Control of the radar aerial elevation. Data are collected during azimuth scans at four basic elevations (nominally at 1·5°, 0·5°, 2·5° and 4°) every 5 minutes. During the lowest scan the elevation may be changed a little as a function of azimuth in order to lift the beam clear of minor obstructions.
- Input of digital amplitude data previously derived by range integration of analogue radar signals (resolution of input data is 750 m, 0·1°). Amplitude data averaged in azimuth (resolution 750 m, 1·0°).
- Correction for occultation of the beam by intervening hills and obstacles.
- Elimination of ground clutter by comparison with a stored clutter map followed by interpolation to derive weather signals in the cluttered areas.
- Correction for attenuation through rain for the 5·6 cm radars (attenuation by rain is negligible for the 10 cm radars).
- Conversion of radar reflectivity factor, Z, to rainfall rate, R, using the standard relationship $Z = 200\ R^{1.6}$.
- Averaging in range (resolution 1·5 km, 1·0°).
- Range normalization for ranges beyond 50 km (for ranges less than 50 km the normalization is applied via hardware).
- Conversion from a large number of polar cells to a relatively small number of Cartesian cells on both 2 km and 5 km grids. (2 km grid is derived for the 0·5° elevation scan only out to a maximum range of 50 km for the Camborne, Upavon and Clee Hill radars and 75 km for the Hameldon Hill radar; 5 km grid out to 210 km maximum range at each elevation scan except 4° for which the maximum range is 105 km and 2·5° for which the maximum range is 140 km.)
- Insertion of data from higher elevation scans into badly cluttered parts of the lowest elevation data grid (referred to as the 'multi-beam' task); this is a way of overcoming the problem of extensive areas of ground clutter close to a radar site.
- Calibration of the radar using data telemetered from several rain-gauge sites at different ranges from the radar.
- Conversion to 8-bit float notation in order to reduce the amount of storage space (magnetic tape, computer core, etc.) needed for the data grids.
- Data written to 9-track, 800 bpi magnetic tape (7-inch diameter spools, 600 ft tape), the data being zero packed, and areas with no data in the corner of the Cartesian grid being removed. Data integrated over subcatchments are also written to tape. These tapes are sent to Malvern about 10 days after recording for archiving.
- Output to local users of 3-bit picture data and rainfall totals for subcatchment areas integrated over a specified period (e.g. 15 minutes, 1 hour, 24 hours).
- Output of 8-bit data to Malvern including a repeat transmission which is used in an error-checking routine at Malvern (Appendix B).

3.2 *Data formats and types of terminal*

In the Pilot Project at present data are distributed to selected Meteorological Offices and Water Authorities direct from individual radars (section 2.2). It is planned that data will also be distributed to some users after further processing (i.e. the compositing of data from individual sites, and analysis by a forecaster using the Display computer) at Malvern.

The data are formatted as a stream of 3-bit (8 intensity levels including zero) numbers framed by various sequences of control characters, and may be displayed by the user on a colour monitor using a commercially available electronic store designed by the RSRE (Ball *et al.*, 1976). This store, in the form currently available from Jasmin Electronics Ltd, may hold up to nine pictures from individual radars or four pictures of the radar composite which may be replayed in time-lapse sequence. Subcatchment data transmitted from the individual radars may be displayed on a simple strip printer (Ball *et al.*, 1979b). Data may also be recorded and replayed by users using an audio cassette recorder and a modem (modulator and demodulator unit). Figure 5 shows the maximum hardware configuration that a user could have.

3.3 *Compositing data from several radars at Malvern*

Ball *et al.* (1979b) describe software developed by the Royal Signals and Radar Establishment (RSRE) to produce, in near-real-time, a composite picture of surface rainfall based on data from three radar sites. A form of packet switching communications system was developed initially to enable control of the network as a whole to be passed from one radar site to another if necessary (Taylor, 1975). However, the need for any radar site to be able to control total network operation is not great. Moreover, it is accepted that radars which are part of separate projects (e.g. the Hameldon Hill radar) must not be interfered with by other sites. Thus, following the suggestion by Ball *et al.* (1979b) that the network communications could be simplified, we have developed new software for use in the network computer at Malvern, and in the computers at the radar sites, which uses the error-checking techniques described in Appendix B. Essentially, the network computer software adopts a passive role, 'listening' for data from the radars within a pre-set temporal window every 15 minutes.

At Malvern the data from several radar sites are processed simultaneously every 15 minutes on an interrupt basis. At present four radars are involved, but the software has been written to cope with data from at least eight radar sites. We now give a broad summary of the software which has been written to composite the data from several radars in real time; the details of the software will be described by Larke and Collier (1980). The main tasks, in the order in which they are carried out, are summarized as follows:

- Simultaneous input of data from radar sites using a 'dual buffer' technique for each site. Two buffers are allocated to each site so that data may be received in one, whilst data are being transferred to the computer disc from the other. This avoids any possible loss of data during disc transfers.
- Error-checking routines to assess whether data from the repeat transmissions are required (Appendix B).
- Empty buffers for each site alternately to the computer disc as the data are received.
- Read the data on disc (in 8-bit format) into the computer core, placing the data from each site in a composite 128 × 128, 5 km grid. A stored map gives the boundaries between radar sites.
- Write the composite data (in a 128 × 128, 5 km grid) to 9-track, 800 bpi magnetic tape (do the same for the data from each individual site on 84 × 84, 5 km grids, as back-up for the on-site tape recordings).
- Output the composite picture in 3-bit format to a local display at Malvern and eventually to other users elsewhere.

3.4 *Satellite data processing*

The need in the Pilot Project is for infra-red and visible satellite data (and combinations thereof) in digital format covering part of the British Isles and surrounding areas. Therefore the SDUS Meteosat data received at Lasham are transmitted to Met O 22 at Bracknell, where the data are digitized on a

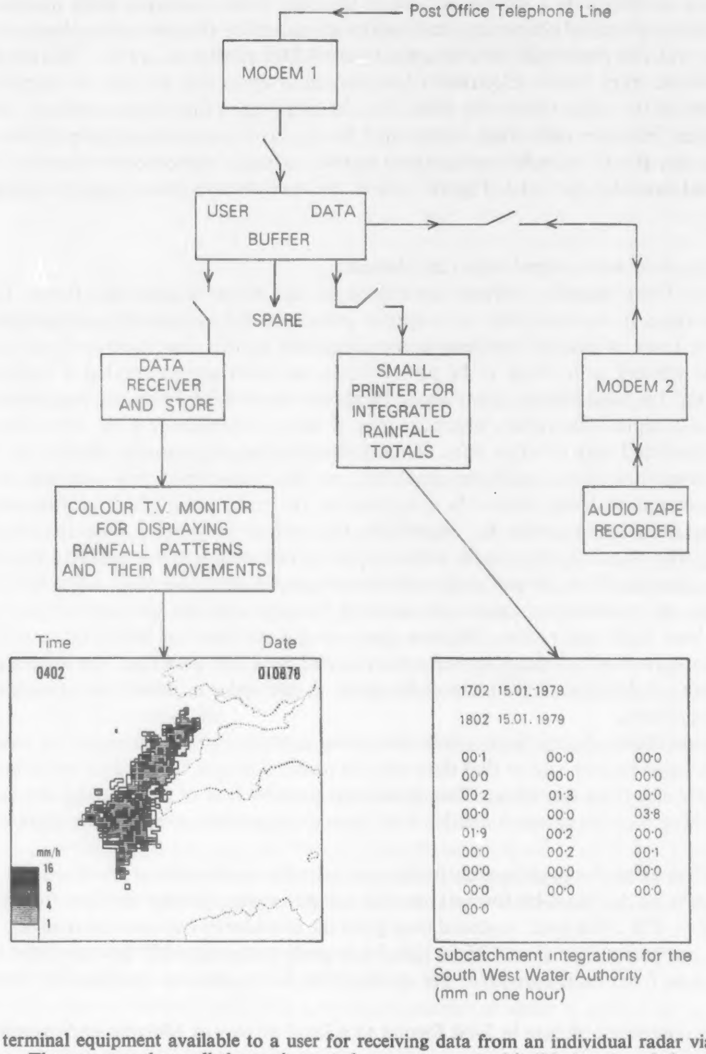

Figure 5. The terminal equipment available to a user for receiving data from an individual radar via a Post Office telephone line. The user may have all the equipment shown, or a part of it (Modem 1 and the user data buffer are mandatory). Examples of the individual radar picture data and subcatchment output are also shown.

PDP11/60 computer, the area required being extracted and projected on to an extended National Grid (for compatibility with the radar data), and transmitted to Malvern, where they arrive about 5 minutes after being received at Lasham. These data can be sent, either on a 128 × 128, 10 km grid formatted in the same way as the radar data transmitted from radar sites, or on a 256 × 256, 5 km grid in a packed format. The 128 × 128 grid format enables the data to be displayed on a colour monitor using an electronic store (the Jasmin store display) for radar data as described by Ball *et al.* (1979a) (see section 3.2). The 256 × 256 grid format, the normal mode of transmission to Malvern, has been specified so that the data may be input to a computer-driven display system (the Display computer in Figure 3) for further processing. Data are transmitted from Darmstadt every half hour. Following an improvement in the schedule in June 1979, each picture was received at Malvern about 15 minutes after the observation time. The satellite data may be used by the Forecasting Techniques Group of the Met O RRL as soon as they are received in the Display computer (section 3.5) by using a series of simple teletype commands.

3.5 *The Malvern computer-driven radar-cum-satellite display*

The *total* system of processing, analysing and forecasting using radar and satellite data has been discussed by Browning (1979), and a framework in which this system could be developed has been proposed (Browning, 1980). Central to the plan is the need for a centralized computer-driven interactive display system, and such a system is being developed at Malvern (the Display computer in Figure 3).

The main tasks carried out by forecasters which require an interactive display are:

- *Meteorological analysis:* i.e. the generation of quality-controlled radar composite pictures and analysed radar-cum-satellite actuals.
- *Very-short-range forecasting of precipitation* using the radar–satellite combination as the basic data, and both objective and subjective forecasting techniques.
- *Tailoring and dissemination of actual and forecast precipitation information* using video displays, computer-to-computer links, etc. (Because the data are analysed in a digital format, dissemination via digital communications can be accomplished with a minimum delay between the production of a product and its reception by a user.)

It will take a considerable time to develop in full the required software and to optimize the way in which forecasters implement the various tasks. At present only simple software exists, which enables the radar and satellite data received at Malvern to be stored on a computer disc, combined, and displayed separately or in combination. The radar and satellite data are displayed using an electronic store developed by the RSRE, known as the Fast Update Store (Ball, 1979). Data are passed to this store very rapidly by a Direct Memory Access (DMA) transfer from the computer core, and may be displayed on either a 256 × 256 grid or a 128 × 128 grid. Sequences of more than 50 radar or satellite pictures (or a combination of both) may be replayed at variable speed. Forecasters may select pictures using a variety of software facilities. The details of the analysis and forecasting procedures will be the subject of future reports.

4. Off-line data processing

The aims of the Pilot Project include research into methods of producing short-period forecasts of precipitation, and fundamental research into the structure, mechanism and behaviour of meteorological systems. In order to achieve these aims, it is necessary to establish an extensive meteorological data base. A requirement exists (Browning, 1977) for an archive comprising radar, satellite and more conventional meteorological data. Such an archive is being established at Malvern (Table I). It will

Table I. *Summary of the principal data archives being established in the Pilot Project*

Data source	Archives on 9-track magnetic tape held at Malvern	Archives on media other than magnetic tape held at Malvern.
1. Data from individual radars recorded on-site—instantaneous rainfall rates.	Data from four low-elevation angles out to a range of 210 km for the two lowest elevations, for the next elevation 140 km, and for the highest elevation 105 km on a 5 km grid (84 × 84 matrix). There are 208 intensity levels. Data are composited from data at several elevations in order to produce the 'optimum' surface precipitation field. Data from this precipitation field are also available on a 2 km grid out to 50 km range for the Camborne, Upavon and Clee Hill radars, and to 75 km range for the Hameldon Hill radar. Data from each elevation are recorded on a five-minute cycle.	
2. Data from individual radars—hourly rainfall totals.	Data from the 'optimum' surface precipitation field on both the 2 km and 5 km grids integrated over clock hours.	
3. Radar network data composited at Malvern—instantaneous rainfall rates.	Data from the 'optimum' surface precipitation field on the 5 km grid for each radar being used to form the composite. One picture from each site is received every 15 minutes. The radar composite pictures on a 128 × 128 grid are also recorded.	
4. Radar-compatible satellite IR and VIS data (small area).	Data are recorded on a 256 × 256 matrix of 5 km squares with 8 levels of intensity; data interval 30 minutes.	
5. Rain-gauge data.	Hourly totals from some 140 rain-gauges, and daily totals from about 4000 rain-gauges covering the project area (obtained from the Systems Development Branch of the Meteorological Office at Bracknell).	
6. Facsimile satellite IR and VIS data (large area).		Facsimile displays for interesting cases only; data interval 30 minutes for Meteosat, 6 hours for TIROS-N.
7. Serial radiosonde data from Malvern.		Radiosonde data on hard copy during the passage of some precipitation systems.
8. Vertical precipitation profiles from Malvern (not yet available).		Height–time printouts of precipitation echo intensity.

include rain-gauge data, facsimile satellite IR and VIS data, occasional serial radiosonde data (from a Mk 3 radiosonde system at Malvern), and data from a planned vertically pointing radar situated at Malvern. This is in addition to the instantaneous and time-integrated digital radar and satellite data.

In order to ensure that the radar data received at Malvern are of acceptable quality, a significant amount of effort has been put into the development of quality control procedures. These procedures involve the comparison, both off-line and in near-real-time, of the radar data with rain-gauge data, and the early identification of the effects of hardware faults by the Met O RRL team of forecasters. The off-line assessments of the quality of the radar data are based on hour-by-hour comparisons of the integrated radar data from each radar in the network (one picture every five minutes) with data from a network of some 40 autographic rain-gauges. The archive of rain-gauge data is held at Malvern for this specific purpose. These comparisons allow the effects of the bright band, anomalous propagation, and long-term radar calibration drift to be identified.

In order to achieve easy reference to data, one radar composite picture and one satellite picture per hour are selected from the archives for routine reproduction as hard copy (line-printer output). These hard-copy files, known as the 'condensed data set', provide the means of easily and quickly identifying cases of particular interest. An example of a printout is given in Figure 6. The condensed data set is being updated daily. On request, other data, including hourly integrations of the radar site data, may be made available as hard copy or as a magnetic-tape copy. The area integrations (subcatchments) recorded on the magnetic tapes at the radar sites are also available.

Interest in these archived data has been expressed by several Water Authorities (principally the North West Water Authority, Wessex Water Authority, Severn–Trent Water Authority and the South West Water Authority) who hope to carry out off-line case studies of hydrologically interesting events using numerical models of river catchments and empirical control rules. Arrangements have also been made to supply hourly integrations of the surface precipitation field for each radar, based on the data acquired at five-minute intervals, to the Agriculture and Hydrometeorology Branch (Met O 8) of the Meteorological Office at Bracknell. These data will be combined with available autographic and daily rain-gauge data to produce a data base which should enable practical hydrometeorological research to be carried out. This will include an assessment of the rain-gauge network densities needed in the presence of radar data to satisfy particular users of rainfall information.

5. Concluding remarks

The data-processing system described in this paper has been producing data only since June 1979 although data of variable quality from one or two individual radar sites have been available for much longer than this (since May 1978 in the case of the Camborne radar, and since February 1979 for the Upavon radar). The basic software package at the radar sites has now (December 1979) operated for over 18 months, although several improvements have been made to it during this period. Satellite data were received at Malvern (although not continuously recorded) from May 1978 until November 1979. The network software, and the first version of the software to combine radar and satellite data, have been extensively tested off-line, and have been in continuous use since June 1979. Over the next few years it is expected that the radar system will undergo development, such that the data it produces will steadily improve in quality. There will be a steady evolution towards greater quantitativeness. Improvements will be made, for example, in the rain-gauge calibration procedures, and in correcting the data for the effects of the bright band.

More than 5×10^6 bits of information are now being processed each hour in the total system. At present this includes data from only four radars plus digital IR and VIS images from Meteosat. However, a further radar site in the London area is already in the planning stage, and the FRONTIERS

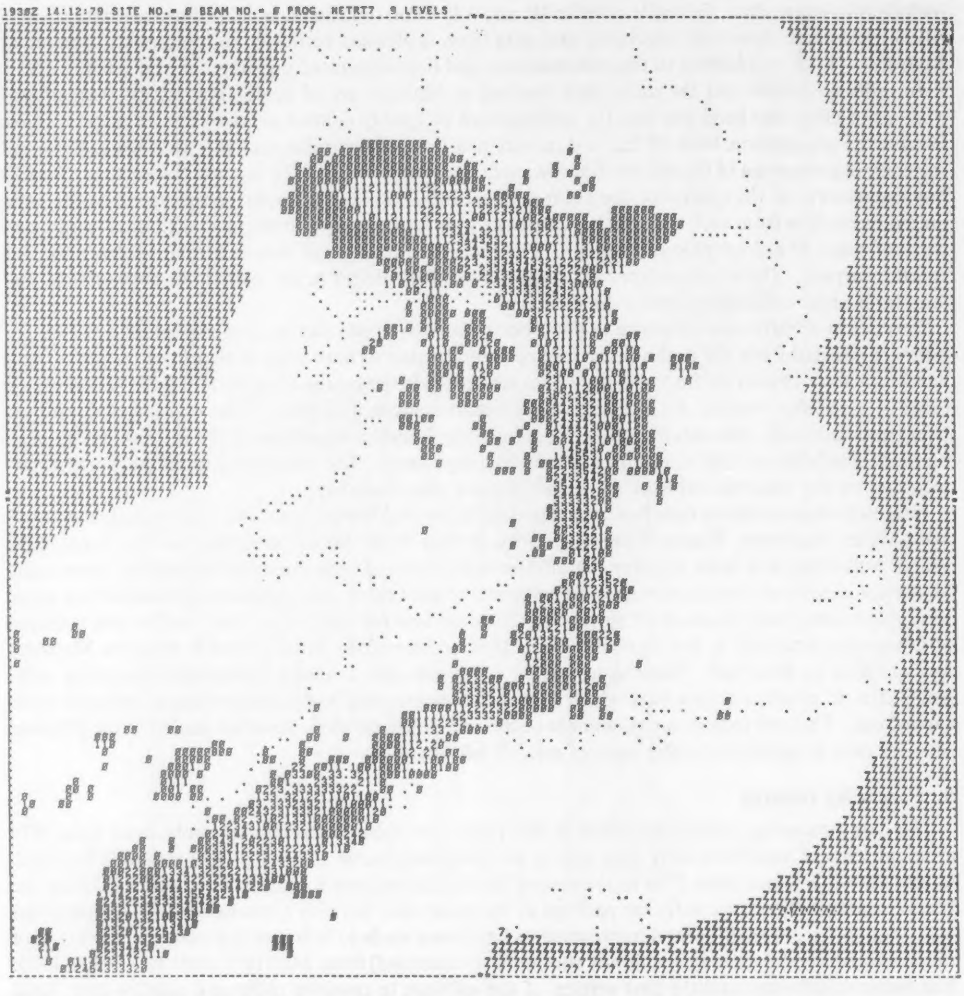

Figure 6. An example of the hard-copy product forming the 'condensed data set'. The example is a radar composite picture made up of data from the Camborne, Upavon and Clee Hill radars at 1930 GMT on 14 December 1979. Different symbols represent different rainfall rates as shown. The coastline is shown dotted. The area not observed with the radars is shown by a pattern of '7's. The key to the symbols is as follows:

Symbol	Rainfall rate (mm h^{-1})	Symbol	Rainfall rate (mm h^{-1})
Blank	0·0	3	4·0 to $<$8·0
Ø	$>$0 to $<$1·0	4	8·0 to $<$16·0
1	1·0 to $<$2·0	5	16·0 to $<$32·0
2	2·0 to $<$4·0	6	32·0 to $<$64·0

strategy calls for the future use of digital PDUS data from Meteosat, cloud-texture information from polar-orbiting satellites, and conventional synoptic data. Clearly the data-processing system will expand throughout the next few years of the Pilot Project.

Finally, the new generation of mesoscale numerical weather prediction (NWP) models (Carpenter *et al.*, 1978), being developed in parallel with the Pilot Project, is likely to require new sources of data for model initialization. Browning (1979) has pointed out how the FRONTIERS strategy relates to these NWP models, and has stressed the need to investigate how radar and satellite data together might be used to define the humidity field over a wide area, in a timely and more accurate fashion than that attainable by using more conventional data. The data archives being established in the Pilot Project provide the necessary data base and the opportunity to investigate how this can be achieved.

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Appendix A. The North West Radar Project

The North West Radar Project is a co-operative venture supported by the Meteorological Office, the North West Water Authority, the Water Research Centre, the Central Water Planning Unit, and the Ministry of Agriculture, Fisheries and Food. The principal aims of the Project are to establish a new unmanned C-band radar on Hameldon Hill near Burnley in Lancashire (Figure 1), to integrate the radar data into the North West Water Authority's Regional Communications System (RCS), and to assess the usefulness of the radar data for operational hydrological and meteorological forecasting.

A full description of the Project aims and the data communications system has been given by Collier *et al.* (1980). Data from the radar computer at Hameldon Hill are continuously transmitted to Malvern, where they are recorded using a dedicated PDP11/34 computer which passes one picture every 15 minutes to the Network PDP11/40 computer (Figure 3). Data are also supplied to the river control centre at Catterall (Franklaw treatment works), to the NWWA Rivers Division at Warrington, and to the Meteorological Office at Manchester Airport. Communication between Hameldon Hill, Warrington and Catterall (Figure 3) is accomplished by the use of the RCS microwave communications system. The communications links to Catterall, Warrington and to Malvern are from computer to computer, but the data sent to Manchester Airport via Warrington are displayed at Manchester Airport using the Jasmin store facility (Figure 5).

Appendix B. Error checking

Since the error rates on leased Post Office lines are low (usually less than one bit in 10^6 bits), no special error checking is carried out within the user terminal equipment used in conjunction with data transmissions from the radar sites. The data transmissions are continuously repeated for the 15-minute period between the data updates. Errors observed by the users in one transmission may be overwritten by display of the data in the next transmission. However, there is not time in the radar site software for more than two transmissions per 15 minutes of the 8-bit synchronous data to the Met O RRL at Malvern. Further transmissions within a period of 15 minutes would delay the production of the radar composite by more than 5 minutes. For these data an error-checking procedure based upon use of the automatic repeat transmission sequence has been adopted.

If an error is detected in the first transmission by the network software at Malvern which examines special block check characters generated at the radar sites, then the error may be corrected by receipt of the appropriate data blocks in the second transmission within one minute. Errors in the actual precipitation intensity values, rather than the block check characters, will not be detected until the data are displayed. No special checking code (such as the Hamming code) is used, and the procedure is a simple form of the Forward Error Correction (FEC) technique with a high degree of data redundancy, and a low (*c.* 10%) usage of the communications line. For the Hameldon Hill radar system this procedure is modified as all data processed are continually transmitted to Malvern for recording, and there is no time for repeat transmissions. In this case errors detected by examination of the block check characters are flagged but cannot be corrected.

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Radiation reference scales

By B. R. May

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Summary

The origin of the absolute reference scales for solar radiation measurements used in the past, and the relationships between them, are described in this paper. The calibrations for the Meteorological Office National Reference pyrheliometers, which have been used to refer radiation measurements in the United Kingdom to these scales, are discussed. The implications for radiation measurements of the most recent WMO-recommended change in scale, from the International Pyrheliometric Scale (1956) to the World Radiometric Reference, is described.

1. History

For many purposes it is required that measured values of radiation* are correct in the absolute sense, to be achieved by observing with instruments whose calibration can be traced ultimately to an absolute reference. In the early years of this century two main types of absolute instruments were available—the Swedish Ångström electrical compensation pyrheliometer and the Smithsonian Abbot water-flow pyrheliometer, defining the Ångström (1905) and Smithsonian (1913) radiation scales respectively. By indirect comparison it was found that these scales were not in agreement, the Smithsonian instrument registering a greater radiation than the Ångström instrument when they observed the same source; initially differences ranging from 3 to 6 per cent were observed by various workers with a mean of about 3·5 per cent. As a consequence, in 1956 an International Radiation Conference recommended that radiation measurements on a scale of greater absolute accuracy could be obtained by decreasing measurements made on the Smithsonian scale by 2 per cent and increasing those made on the Ångström scale by 1·5 per cent. This new scale was called the International Pyrheliometric Scale 1956 (IPS 1956); see, for example, Drummond (1970) and Special Committee for the International Geophysical Year (1958).

However, further measurements of the difference between the Ångström and Smithsonian scales of 4·6 per cent by Latimer (1973) and 5·0 per cent by Fröhlich (1975), in combination with the previous measurements, confirmed that the mean difference was closer to 4·5 per cent. Consequently corrected radiation measurements generated from these two original scales would still differ by about 1 per cent on average. Thus the IPS 1956 was not a well-defined scale and effectively two versions existed resulting from the use of the recommended corrections to measurements made on the Smithsonian and Ångström scales.

To ensure the comparability of radiation measurements internationally the World Meteorological Organization (WMO) recommended the establishment of a World Radiation Centre (at Davos in Switzerland) to calibrate a group of reference pyrheliometers on the basis of IPS (1956) and a system of regional and national radiation centres each with their pyrheliometers. International and Regional

* The word *radiation* is used for the general physical phenomenon, *irradiation* for a numerical measure of energy, and *irradiance* for a numerical measure of power, i.e. the time derivative of irradiation.

pyrheliometric comparisons (IPCs and RPCs) have been held to determine regularly the WMO-recommended calibrations for each instrument on the IPS (1956) scale. WMO appointed Kew Observatory as a Regional Radiation Centre, and hence, National Radiation Centre (NRC) for the UK. At the beginning of 1974 the NRC was transferred from Kew to Beaufort Park, the experimental site of the Meteorological Office at Bracknell.

Initially the IPS (1956) was maintained at Davos by selected Ångström pyrheliometers built to the Swedish design and there are indications from the consistency with the UK National Standard (see table on p. 18) that over the period from 1958 to 1964 the scale changed by less than 0·4 per cent. Subsequently the IPS (1956) was maintained at Davos by a mixed group of Ångström pyrheliometers of the Swedish and American (Eppley) designs, which are slightly different. This resulted in a change in the IPS (1956) which has been attributed to the influence of circumsolar radiation on measurements made with these pyrheliometers whose fields of view are different from and greater than the 0·5 degree apparent diameter of the sun. Calibrations of the Meteorological Office Ångström pyrheliometer number 583 in Stockholm and Davos indicate that irradiances measured with respect to the Swedish IPS (1956) (i.e. the Ångström scale adjusted by plus 1·5 per cent) need to be reduced by about 1·6 per cent to make them agree with those measured on the IPS (1956) as that scale was established at the 1975 IPC IV at Davos.

During the early 1960s improved absolute radiometers using the absorbing-cavity principle were being developed, and theoretical and experimental evidence indicated that their observations of radiation were more self-consistent and closer to the true value than those of previous pyrheliometers. Comparative measurements between cavity radiometers and pyrheliometers deriving their calibrations from IPS (1956) confirmed that the IPS (1956) as realized at international comparisons in 1970 and 1975 did not agree with the original definition of IPS (1956) which should have been in good agreement with the radiometer measurements; for details of these differences see Fröhlich (1975), Rodhe (1975) and Latimer (1973). After a large number of comparisons between various models of absolute cavity radiometers, recommendations were put forward that a new scale of radiation known as the World Radiometric Reference (WRR) should be brought into use. Details of the experimental basis of this scale are given by Fröhlich (1977) (Fröhlich refers to WRR as the Solar Constant Reference Scale). The WRR specified in SI units represents the absolute value of irradiance with an estimated accuracy of better than ±0·3 per cent.

The effect of the change in scale from IPS (1956) to WRR is to increase by 2·2 per cent the values of irradiances obtained from instruments calibrated on the IPS (1956) as that scale was realized at the IPC IV at Davos in 1975. WMO recommend that WRR be brought into use from 1 January 1981, or that it be brought into use on a provisional basis before that date provided care is taken to indicate the relevant scale to which data are related.

2. Radiation scales and Meteorological Office practice

Up to 1967 three old models of the Ångström pyrheliometers, numbers 24, 100A and 100B, were used as the UK reference instruments. Modern Swedish Ångström pyrheliometers numbers 583 and 587 were obtained in 1967 and 1968 respectively to replace the older instruments. The comparisons between the UK reference pyrheliometers and the results of the international comparisons show that the instruments 100B and 583 have been very stable and consequently they have been regarded as the primary reference instruments.

Up to 1957 the instrument Å100B was calibrated in Sweden and subsequently at Davos and was also submitted to two international comparisons at Davos; the instrument Å583 received an initial calibration in Sweden and thereafter took part in four international comparisons at Davos and Carpentras, in

France. The calibrations (in W m^{-2} $(amp)^{-2}$ on the IPS (1956) scale, unless stated otherwise) determined for these instruments are:

Place	Year	Instrument Å100B	Å583
Sweden	1956	1015 on Å (1905) scale = 1030	
Davos	1958	1032	
Davos	1959 (IPC I)	1034	
Davos	1964 (IPC II)	1034	
Sweden	1968		5950
Carpentras	1969 (RPC II)		5820
Davos	1970 (IPC III)		5861
Davos	1975 (IPC IV)		5856 (= 5985 on WRR)
Carpentras	1978		5849

On the assumption that the IPS (1956) scale against which both instruments were calibrated in Sweden was unchanged between 1956 and 1968, the relative change of IPS (1956) as maintained at Davos over the period 1968–75 and revealed at international comparisons can be seen from these calibration figures.

All measurements made in the Meteorological Office before 1 January 1957 were related to the Ångström (1905) scale but have been increased by 1·5 per cent to make them conform to the IPS (1956) scale as it was understood at that time.

Because of the uncertainty in the constancy of the IPS (1956) and the likelihood that a new radiation scale such as the WRR would be close to the IPS (1956) as maintained in Sweden, the Meteorological Office has always used the value of 5950 W m^{-2} $(amp)^{-2}$ for Å583. The effect of this is that according to WMO recommendations following the 1975 IPC IV, all Meteorological Office-determined and archived values of irradiation are 1·6 per cent too large relative to the IPS (1956) as realized in 1975 but only 0·6 per cent too small relative to the WRR. On the WRR scale the calibration coefficient of Å583 is 5985 W m^{-2} $(amp)^{-2}$.

In 1977 a cavity radiometer, number TMI 6764, was obtained to supplement the Office's Ångström pyrheliometer. It is of a type designed by J. M. Kendall and manufactured in the USA, and indicates irradiance directly in units of mW cm^{-2}. This radiometer was submitted for the first time to an international comparison in Carpentras in 1978 at which it was established that it has a calibration factor of 0·9975, i.e. it registers only 0·25 per cent too low with reference to the WRR as determined by a direct comparison with an absolute cavity radiometer from Davos and indirectly against (with appropriate corrections) Ångström pyrheliometers.

3. Adoption of WRR

The Meteorological Office has adopted the option given by WMO and made the change-over to WRR on 1 January 1980. From that date all calibration factors for radiation instruments are related to the WRR. All stations submitting data to the Office have been advised to adjust the already established calibration factors of their instruments to the new scale. All the instruments used by the Office and by co-operating stations will in time be re-calibrated to the new scale. Archived data up to 31 December 1979 will not be amended to WRR but all data will be annotated as to the radiation scale used. The difference of 0·6 per cent between the new scale and that previously used is considered sufficiently small compared with the accuracy of the measurements as not to warrant changing existing archived data.

If the change in the scale of reference is considered important by any user of data or instruments calibrated by the Meteorological Office, this note gives sufficient information for the necessary adjustments to be made.

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Noctilucent clouds over western Europe during 1979

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Table I summarizes the observations of noctilucent cloud (NLC) over western Europe during 1979 which have been reported to the Department of Meteorology, University of Edinburgh.

The times given in the second column of the Table are not necessarily the duration of the display, though appearance and disappearance times are referred to in the Notes where known. In the third column brief notes of the displays enlarge on the facts listed in other columns—NLC forms discernible, tropospheric cloud conditions, photographs and sketches available. Co-ordinates of the observing stations and selected details of elevation and azimuth appear in the remaining columns.

With the inclusion of Icelandic and Swedish information the northern hemisphere observing 'season', during which favourable viewing conditions for NLC last for a few hours centred on local midnight, is extended from about mid-April to late August. NLC occurrence outwith this season cannot be ruled out but it would be particularly helpful to have photographs referring to any such reports.

The supply of positive information during the 1979 observing season was perhaps dependent to an even greater extent than usual on the professional meteorological observer. In the 'unsocial' hours he detected the presence of the clouds during temporary, often only local, breaks in tropospheric cloud cover, on nights which the voluntary observer would have deemed unsuitable.

Forty-three sightings are listed for the 1979 season—many being no more than recognition of the presence of NLC by experienced observers, through breaks in tropospheric clouds.

On 10/11 July the most widely reported display occurred—the same date as the main display of the previous year. Photographs were taken at Milngavie at 10/15 minute intervals between 2145 and 0200 and show the development and movement of the cloud field; photographs were also taken at Edinburgh at 2315. 'Impossible' conditions for the most part prevented any sighting from Swedish stations on this night.

Routine hourly observations were made at 16 meteorological stations in the United Kingdom, 4 in Sweden, and at Reykjavik in Iceland when darkness permitted, and the sky conditions detailed in these form an important contribution to the data collection, particularly where conditions are sufficiently clear to allow a decision of 'No NLC'. 'Negative' nights are particularly significant during a possibly unbroken series of NLC appearances, or as a helpful point of reference when NLC is suspected by another observer in the vicinity. Positive reports, some accompanied by sketches, came from the 4 Swedish stations and a Swedish aircraft, 13 UK meteorological stations, 2 stations of the Irish Meteorological Service, the Peterhead Coastguard, and from voluntary observers at Douglas, Newton Stewart, Milngavie, Newton Mearns, Alrø and Fiane. A simultaneous auroral display was seen from Alrø on 26/27 July. The most southerly display was seen on 2/3 July from Bedford and Exeter.

In Edinburgh, time-lapse photography was carried out throughout the observing season; on occasions NLC was detected by eye and still photographs were taken (13/14 and 17/18 June, 7/8, 8/9 and 10/11 July). Photographs were received from Milngavie (10/11 and 14/15 July), Malin Head (4/5 July), Alrø (26/27 July) and Reykjavik (22/23 August), all of which we acknowledge with thanks.

The co-operation of the meteorological authorities of Denmark, Iceland, Ireland, Sweden and the United Kingdom, and voluntary observers in Britain, Denmark and Norway is gratefully acknowledged.

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Table I. *Displays of noctilucent clouds over western Europe during* 1979

Date—night of	Times UT	Notes	Station position	Time UT	Max. elev. (degrees)	Limiting azimuths (degrees)
8/9 Apr.	0100	Bright NLC veil visible Sundsvall [? Moonlit cirrus].	62·5°N 17·5°E	0100	10	060–090
13/14 May	0200	Boulmer reported possible NLC behind tropospheric cloud.	55·5°N 01·5°W			045
15/16	2100–2340	Persistent display of very bright NLC billows in zenith, receding and fading, recorded Sundsvall.	62·5°N 17·5°E	2100	90	
				2250	70	350, 200
				2310	45	350, 200
				2340	40	340, 040
18/19	2400	NLC bands visible from Wick for the one observation. Tropospheric cloud and snow shower prevented any later recognition.	58·5°N 03°W	2400	12	360–010
23/24	0130	Bright band of NLC distinguishable against very bright—probably NLC veil—background.	55·5°N 01·5°W	0130	3	010–060
25/26	0045, 0100	From Edinburgh report of probable NLC—low elevation; very faint glow seen Claremorris.	56°N 03°W	0045		360
			53·5°N 09°W	0100		345
27/28	2300	Faint band of NLC visible Boulmer; band described as 'boomerang'-shaped.	55·5°N 01·5°W	2300	7	340
28/29	2320, 2330	NLC suspected present at 2320; revealed 2330 by breaking up of tropospheric cloud.	56°N 03°W	2330	10+	330–030
30/31	2245–0030	Medium brightness NLC bands to high elevation seen from Gotland.	57·5°N 18·5°E	2300	70	320–020
1/2 June	2230, 2300	From Edinburgh NLC suspected visible at low level behind bank of haze; seen more clearly as band of NLC from Machrihanish.	56°N 03°W	2230	5	
			55·5°N 05·5°W	2300	5	340
			55°N 04·5°W	2300		
2/3	2400–0230	Benbecula reported sky clear 2300. At 2400 bright low-level glow visible which became very bright 0100, with globular, or knotted formation noted at centre.	57·5°N 07·5°W	2400	5	310–010
				0200	10	
			56°N 03°W	2350		360
		Faded into light sky at 0230. Report from Umeå for 2055 thought unlikely to be NLC because of sky lightness.	[64°N 20·5°E	2055	20	310–330]
9/10	2330	NLC suspected present behind bank of tropospheric cloud (approx. to 15°).	56°N 03°W			
			55°N 04·5°W	2300		
10/11	2315–2400	From Jönköping report of high elevation medium brightness NLC veil. No NLC visible 0015.	58°N 14°E	2315	60	330–030
				2345	60	030–060
13/14	2350	From Edinburgh NLC suspected visible through temporary breaks in tropospheric cloud. Still photographs.	56°N 03°W			
16/17	0100, 0200	Report from Kinloss of extensive stretch of possible NLC, from 17° to 140°, bands having E–W orientation south of zenith and N–S to north of zenith. Later report was of small patches overhead.	57·5°N 03·5°W	0100	140	
				0200	90	
17/18	2300	From Edinburgh NLC seen extending above low bank of tropospheric cloud. Still photographs.	56°N 03°W	2300	10+	360
			55°N 04·5°W	2205		
18/19	2350, 0052	NLC bands and billows of medium brightness seen from Newcastle.	55°N 01·5°W	2350	30	340–020
				0052	30	340–020
19/20	2215, 2400	Possible NLC visible Edinburgh, and through patches of cirrus at Machrihanish.	56°N 03°W	2215	45	
			55·5°N 05·5°W			045
22/23	.. 2400, 0100	Extensive area of rippled formation visible Benbecula before 2400 to high elevation. Fainter, formless patches to N.	57·5°N 07·5°W	2400	50	345
24/25	0100–0200	Benbecula and Dyce reported possible NLC, but description of dark lenticular patches with luminous undersides gives rise to doubt if NLC.	57·5°N 07·5°W	0100	35	320–360
				0200	35	320–360
			57°N 02°W	0100		270
				0200		270
30 June/1 July	2400 (approx.)	Medium brightness NLC bands to high elevation seen Jönköping.	58°N 14°E	≈2400	90	340–010
1/2 July	0020–0103	Bright patches of NLC seen NNW and NNE from Douglas, I.O.M. NNW patch constant at 20° elevation. NNE patches spread to elevation of near 40° before fading.	54°N 04·5°W	0020	20	345, 045
				0045	40	045
				0102	20	345, 045
2/3	2140–2235	Classic appearance—bluish-white, tenuous as seen from Exeter with interlaced wispy threads; whirl formation reported from Bedford; of shorter duration than observers considered usual for the rare appearances at these lower latitudes. Later report from Edinburgh of suspected NLC above 'red' horizon.	56°N 03°W	2335		330–030
	2335		52°N 0·5°W	2200	12	340–345
			50·5°N 03·5°W	2145	20	
3/4	2200–0010	From Milngavie report of two definite but weak bands of NLC in western twilight segment. Display decreased in elevation and intensified, the bands sweeping round to give impression of large whorl. NLC also suspected later from Newton Stewart.	56°N 04·5°W	2206	40	315
	0115			0010	12	
			55°N 04·5°W	0115		

* to nearest 0·5 degree.

Date—night of	Times UT	Notes	Station position*	Time UT	Max. elev.	Limiting azimuths
					degrees	
4/5	0130–0150	Faint veil of NLC in NNE seen Malin Head. Tropospheric cloud hampered further viewing. Photograph 0130.	55·5°N 07·5°W	0130	10	016–040
7/8	. . 2400 . .	NLC brightest at 2400; at 0005 tropospheric cloud patches moving to N. Still photographs.	56°N 03°W	2400	10+	330–030
8/9	2400 0015–0018	Bright NLC visible over wide azimuth through breaks in almost complete tropospheric cloud cover from both stations. Photographs—Edinburgh.	56°N 03°W	0015	10	345–045
			55·5°N 05·5°W	2400	8	360
9/10	2350	Lighter sky in N denotes possible NLC. Sky generally clear apart from few patches of tropospheric cloud to N.	56°N 03°W			
10/11	2145–0200	Brightest and most widely reported display of the season; bands in zenith reported from Leuchars and traces of NLC seen in SSE segment at 0200 by observers at Kirkwall. Forms observed—veil, bands, billows herring-bone structure. Photographs from Milngavie taken to show development and movement of fine streaks near N and NE horizon. Brightness 4 recorded at Tiree at 2400 and 0100. Most southerly sighting from Ronaldsway, I.O.M. Photographs—Edinburgh and Milngavie.	59°N 03°W	2300	70	330–030
				2400	70	330–030
				0100		300–360
				0200	135	170
			58·5°N 03°W	2400	25	360
				0100	30	300–010
			57·5°N 02°W			
			57·5°N 03·5°W	2300	16	290–350
				2400	17	300–010
				0100	16	320–045
			57°N 02°W	2340	19	340–040
				0050	21	330–050
			56·5°N 03°W	2315	60	360–020
				2400	80	340–020
				0100	25	240–020
			56·5°N 07°W	2230	15	310–340
				2300	16	290–360
				2400	17	300–010
				0100	13	340–020
				0200	14	330–010
			56°N 03°W	2315		
			56°N 04·5°W	2355	11	360–045
				0040	13	360
				0130	15	360
			54°N 04·5°W	2250	11+	325
				2308	10+	325
				2315	9+	325
13/14	2200, 2300	Both stations viewed NLC in tropospheric cloud breaks; seen as very low level bright band from Aldergrove and only bright sheen from Machrihanish to 18+°.	55·5°N 05·5° W	2300	18+	340–010
			54·5°N 06°W	2200		310–330
				2300	6+	310–345
14/15	2045, 2400, 0100	Veil and banded structure visible (and photographed) Milngavie, through tropospheric cloud interference. Visible Håstrup and Boulmer in breaks in tropospheric cloud. Viewed also from Swedish airliner homing to Gothenburg.	57·5°N 12°E		30	330–060
			56°N 04·5°W	2400	7	360
				0030	10	360
			55·5°N 10°E	2045	6+	315
			55·5°N 01·5°W	2400, 0100	—	360
15/16	2245–2345	Faint veil of NLC and, later, bands, visible southern Sweden to moderately high elevation.	58°N 14°E	2245	40	340–360
				2320	40	330–350
				2345	30	340–360
			57·5°N 12°E	2310		360–060
19/20	2130	Brightness observed through breaks in tropospheric clouds—no further observations possible.	56°N 10°E	2130		
20/21	2055, 2230	Parallel bands of NLC visible through breaks in tropospheric clouds.	56°N 10°E	2055	7	020
21/22	0130	Bright and extensive formation of NLC—bands and cross-billows seen Alrø through large breaks in tropospheric clouds.	56°N 10°E	0130		
24/25	2200	NLC bands and cross-billows at high elevation of 50–90° seen Fiane—solar depression angle (s.d.a.) approx. 10°.	59°N 09°E	2200	90	345
26/27	2200	In Fiane NLC bands parallel W–E at 20° elevation and also in zenith. Almost clear conditions. Farther south in Alrø NLC seen low on horizon and later to increase in elevation and brightness until obscured by dawn light. The display appeared simultaneously with aurora. (Photographs—Alrø.)	59°N 09°E	2200	20	360
				2200	90	
			56°N 10°E	2240	3	
				2400	6	
				0040	10	060
31 July/1 Aug.	2400	Faint veil of NLC seen Aldergrove.	54·5°N 06°W	2400	10	360–030
6/7 Aug.	0300	Single patch of NLC to NNE seen Kinloss. Sky conditions 2200–0200 would have allowed presence of NLC to be identified.	57·5°N 03·5°W	0300	22	040–045
10/11	2220, 2250	Bands of NLC, faint to medium brightness visible Sundsvall.	62·5°N 17·5°E	2220	35	300–360
				2250	30	340–030
11/12	2200, 2300	Wisps of NLC, E of N, seen Kirkwall, disappearing slowly at time of later observation.	59°N 03°W	2200		010
22/23	2230–2330	Photographs taken Reykjavik thought not to be NLC, but suspected sighting n oted.	65°N 22°W			
24/25	2115–0115	Very bright NLC visible Sundsvall, for much of time s.d.a. 10–16°. In zenith and to south of zenith for much of display. Veil, band and billow formation; obscured by tropospheric cloud 0115.	62·5°N 17·5°E	2115	150	170–210
				2215	160	170–280
				2315	150	150–270
				0015	150	180–240
				0045	30	040–090

Reviews

Solar–terrestrial influences on weather and climate, edited by B. M. McCormac and T. A. Seliga. 240 mm × 160 mm, pp. xiii + 346, *illus*. D. Reidel Publishing Company, Dordrecht: Holland/Boston: USA/London: England, 1979. Price Dfl 45, US $24, £21.

This book contains the proceedings of a symposium/workshop held in Ohio State University in August 1978, and documents the progress of the research into the effect of fluctuations in the sun on weather and climate. The research has two parts: correlating atmospheric effects with solar events, and establishing viable physical connections between them. The most convincing paper under the first heading is the presentation of evidence by Mitchell *et al.* for a 22-year cycle of precipitation in the western USA (page 125). However, some of the other papers on solar–terrestrial correlations are less well founded, and until physical connections are established (they are only suggested in this book), the work in this field will remain highly speculative. But the book contains a useful cross-section of current research and some discussion of statistical techniques.

D. E. Parker

Concepts in climatology, by P. R. Crowe. 235 mm × 150 mm, pp. xx + 589, *illus*. Longman Group Ltd, Harlow, 1979. Price £6.50 (paperback student edition).

This is a reprint of a book published in 1971. The only amendments are a satellite photograph on the cover, and a list of errata and afterthoughts inside the cover. Therefore the descriptive sections do not have advantage of the most recent data, and the chapter on climatic change is completely outdated, having no mention of the numerical models and palaeoclimatic investigations of the last ten years.

D. E. Parker

Ice ages: solving the mystery, by John Imbrie and Katherine Palmer Imbrie. 240 mm × 155 mm, pp. 224, *illus*. Macmillan Press, London, 1979. Price £6.95.

This history of research into the ice ages is written in a non-technical style well suited to the general reader. The record begins with a fascinating account of how leading geologists were convinced by the evidence of scratched rocks and erratic boulders that an ice age had occurred. The subsequent discovery of multiple layers of glacial deposits led to the need for a theory of the succession of ice ages, and this book concentrates on what is now known as the Milankovitch theory, that regular changes in the earth's orbit are responsible.

Chapters 4 to 7 deal with the early development by Adhemar and Croll of the astronomical theory of the ice ages. The many personal anecdotes and character sketches enliven the account—and perhaps boost the popular image of the ivory-tower scientist. Thus James Croll could write 'The strong natural tendency of my mind towards abstract thinking somehow unsuited me for the practical details of daily work', and Milankovitch came 'under the spell of infinity'—with the help of a few bottles of wine! Unfortunately in some places the graphic language could mislead. For example 'the wind from the north whipped their faces' (referring to Stone Age hunters) could give the impression that northerly winds were predominant during the ice age, whereas in fact a global cooling caused by changes in the radiation supply would not have required northerly winds: the southerly winds would have been colder than nowadays too.

Milankovitch's aim was to calculate in detail the past and present climates using orbital data to determine the global distribution of incoming solar radiation. The account of his life's work is attractively presented in the book and shows his determination to succeed, even in prison. The authors are

clearly strong advocates of the Milankovitch theory, but before considering it they give a good brief summary of some other theories. However, it would have been fair also to have pointed out the imperfections in the fit of the Milankovitch theory: for example in Figures 38 and 40 the intervals between peaks of warmth are 120 000 years for the most recent cycle but only about 75 000 years in the previous five cycles. The problem of which season's radiation is critical for ice-sheets is given due attention and is left fairly open until near the end of the book when the results of spectral analysis of deep-sea cores are taken to indicate the phase relationships between orbital changes and ice ages. Unfortunately this knowledge does not clarify what mechanisms are involved, so the forecast of the future, generally cautious and balanced, is, for the long term, an extrapolation of periodicities. If the climatic reaction to orbital changes had been perfectly regular this would have been acceptable, but given the irregularities in the past, the forecast should have been worded accordingly.

The first author (J. Imbrie) is one of the leading workers with isotopic variations in deep-sea cores, and the accounts of this work are very clear and intriguing. However, there are a few errors in some of the astronomical sections. For example (see page 71) the excess of daylight over darkness in the northern hemisphere is 168 hours at the North Pole only, and decreases equatorwards. Also the argument on page 75 is suspect: in a given hemisphere the total solar heating per year will be greatest when the earth is nearest the sun in summer, because the variations of $(1 \div (\text{distance to sun})^2)$ will have more effect on the larger quantity involved in summer.

The earlier chapters make mention of the conflict of religious belief and scientific theory. The authors would have done well to state that the conflict is one of basic principles, not of conflicting observations. The basis of all scientific research into the distant past is the principle of 'uniformitarianism', i.e. that the laws of nature have always been the same as they are now. Research could not proceed without such an assumption, and the results should be taken as true in so far as that assumption holds. Belief in God's creative and other activities in the past is not intellectual suicide but the choice of a different set of basic principles.

In summary, the authors have produced an interesting account for the general reader, but it should be read with more discriminating thought and care than the general reader may be likely to take.

D. E. Parker

Notes and news

International Conference on Climate and Offshore Energy Resources, 21–23 October 1980, London—Preliminary Announcement

This conference will be organized jointly by the Society for Underwater Technology, the Royal Meteorological Society, and the American Meteorological Society, and will be held at the Royal Society, 6 Carlton House Terrace, London SW1.

Objectives. To review and discuss, at an interdisciplinary level, recent developments in meteorology and oceanography relevant to the harnessing of offshore energy resources.

To consider, on the basis of current knowledge and understanding of climate, the likely implications for total energy demand and offshore production into the next century.

Opening address by Roy Jenkins, President, Commission of the European Communities.

Conference Dinner. The Conference Dinner will be held on the evening of 22 October 1980 at the Guildhall, City of London. Attendance at the dinner will be available to Conference participants on payment of a charge in addition to the Conference registration fee.

Registration. Attendance at the Conference will be limited to those numbers that can be effectively accommodated by the Royal Society's meeting and catering facilities.

Registration charges are £120.00 per delegate plus £15.00 VAT, and cover:

(1) attendance throughout the Conference;
(2) all available pre-prints;
(3) reports on discussions on papers;
(4) coffees, lunches and teas as indicated in the final program; and
(5) proceedings at an 'at cost' charge.

Conference sessions and subject coverage

Climate, energy and man

Climate and world energy demand (including variations in both space and time).

Lessons from the past (including reference to history of climate, limited resources, environmental pressures, etc.).

Man's impact on climate.

Studying the atmosphere and oceans

The atmosphere—its climate and what influences it.

Oceans and ocean currents—their influence on climate.

Requirements of industry offshore.

Techniques of prediction

Principles of climate modelling (including statistical methods).

Applications of climate modelling.

Prediction using general circulation models.

Offshore energy resources

Exploitation of potential oil and gas resources offshore.

Ocean energy—waves.

Ocean energy—tides and currents.

Offshore thermal energy conversion.

The next century

Which way climate?

The World Climate Program.

How much offshore energy?

Enquiries concerning the Conference should be directed to:

The Executive Secretary,
Royal Meteorological Society,
James Glaisher House,
Grenville Place,
Bracknell,
Berks., RG12 1BX.

Professor Gordon Manley, M.A., D.Sc.

We regret to record the death at Cambridge on 29 January 1980 of Gordon Manley, M.A., D.Sc., Emeritus Professor of Environmental Studies in the University of Lancaster; he was the doyen of British climatologists and in the course of a long and distinguished career received many honours from his fellow meteorologists.

Professor Manley was educated at Queen Elizabeth's School, Blackburn, the University of Manchester, and Gonville and Caius College, Cambridge. His first appointment, in 1925, was to the Meteorological Office, when he became a Junior Professional Assistant at Kew Observatory. After taking part in the North Greenland Expedition of 1926, he resigned from the Office to enter academic life, holding lectureships at the Universities of Birmingham, Durham and Cambridge before becoming Professor of Geography at Bedford College, University of London, in 1948.

He left Bedford College in 1964, when he was already 62 years old, to become the first Professor of Environmental Studies in the new University of Lancaster, retiring from this appointment in 1968 although he continued to maintain a close connection with the University and the work that went on there.

He was awarded the Buchan Prize of the Royal Meteorological Society in 1963 and was Symons Lecturer in 1944. He served as President of the Society from 1945 to 1946 and in 1976 he was elected an Honorary Fellow. From 1955 to 1961 he was Correspondent for Glaciology on the British National Committee for the International Geophysical Year. From 1958 to 1962 he served on the Synoptic, Dynamical and Climatological Subcommittee of the Meteorological Research Committee.

Gordon Manley continued to work until the very end of his life, and indeed a paper on the climatology of the northern Pennines is now being edited for the *Meteorological Magazine* thereby adding to the long list of his publications on weather and climate, in particular those of northern upland Britain. His earlier researches included studies of the helm wind phenomenon of the Cross Fell range in Cumbria and of polar climatology, and while he was at Durham he set up and ran an observing station at Moorhouse in upper Teesdale, at a height of 1825 feet; he played a large part in establishing and directing the activities of the Snow Survey, himself preparing reports for the first two seasons of 1938/39 and 1939/40. In later years he concentrated on historical studies of the British climate, subjecting many long instrumental records to critical examination and adjustment in the light of all the relevant evidence; one outstanding result of this work was his series 'Central England temperatures: monthly means 1959 to 1973' published in final form in 1974 which provides a fundamental source of information for researchers into climatic change. His delightful book, 'Climate and the British Scene', helped to make him known to a wider public than that of professional meteorologists, as did his frequent articles in the *Guardian*.

He was an affable and courteous man, endlessly interested in all manifestations of weather, climate, and climatic change whether real or imagined. He belonged to the generation before that of computers and climate modelling and, perhaps in consequence, would frequently warn his younger listeners that they must maintain contact with reality by thoroughly knowing and understanding their primary sources of data, i.e. the original observations—how reliable they were and how they could be affected by exposure or by human and instrumental errors.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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